Inter-Process Communication:
Message Passing

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(including slides from Kai Li,
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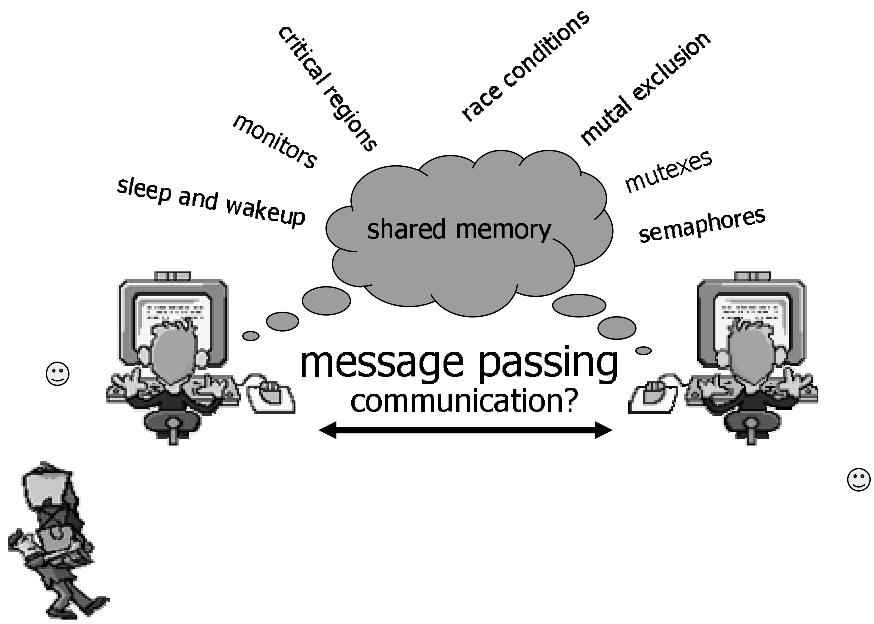
Big Picture



Message Passing API

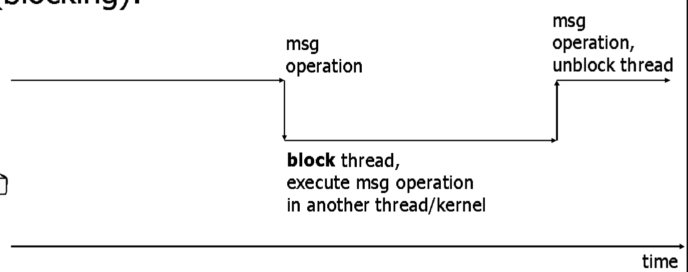
- Generic API
  - `send( dest, &msg )`
  - `recv( src, &msg )`
- What should the "`dest`" and "`src`" be?
  - pid
  - file: e.g. a (named) pipe
  - port: network address, pid, etc
  - no src: receive any message
  - src combines both specific and any
- What should "`msg`" be?
  - Need both buffer and size for a variable sized message

Issues

- Asynchronous vs. synchronous
- Direct vs. indirect
- How are links established?
- Can a link be associated with more than two processes?
- How many links can there be between any pair?
- What is the capacity of a link?
- What is the size of a message?
- Is a link unidirectional or bidirectional?

Asynchronous vs. Synchronous

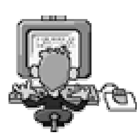
- Synchronous (blocking):

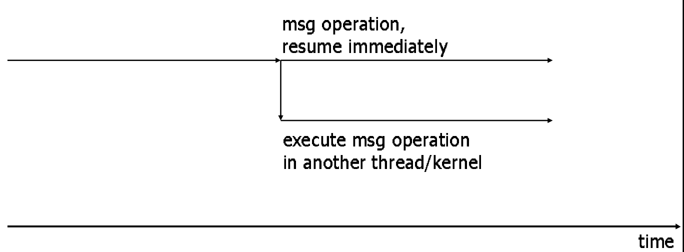


  – thread is blocked until message primitive has been performed
  – may be blocked for a very long time

Asynchronous vs. Synchronous

- Asynchronous (non-blocking):





  – thread gets control back immediately
  – thread can run in parallel other activities
  – thread cannot reuse buffer for message before message is received
  – how to know when to start if blocked on full/empty buffer?
    - poll
    - interrupts/signals
    - …

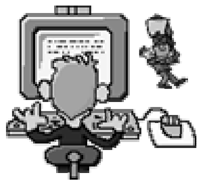
Asynchronous vs. Synchronous

- Send semantic:
  - Synchronous
    - Will not return until data is out of its source memory
    - Block on full buffer
  - Asynchronous
    - Return as soon as initiating its hardware
    - Completion
      - Require application to check status
      - Notify or signal the application
    - Block on full buffer
- Receive semantic:
  - Synchronous
    - Return data if there is a message
    - Block on empty buffer
  - Asynchronous
    - Return data if there is a message
    - Return null if there is no message

Buffering

- No buffering
  - synchronous
  - Sender must wait until the receiver receives the message
  - Rendezvous on each message
- Buffering
  - asynchronous or synchronous
  - Bounded buffer
    - Finite size
    - Sender blocks when the buffer is full
    - Use mesa-monitor to solve the problem?
  - Unbounded buffer
    - "Infinite" size
    - Sender never blocks

Direct Communication



- Must explicitly name the sender/receiver ("`dest`" and "`src`") processes
- A buffer at the receiver
  - More than one process may send messages to the receiver
  - To receive from a specific sender, it requires searching through the whole buffer
- A buffer at each sender
  - A sender may send messages to multiple receivers

Message Passing:
Producer-Consumers Problem

```
void producer(void)
{
   while (TRUE) {
        …
        produce item;
        …
        send( consumer, item );
   }
}
```

```
void consumer(void)
{
   while (TRUE) {
        recv( producer, item );
        …
        consume item;
        …
      }
}
```

Message Passing:
Producer-Consumers Problem with N messages

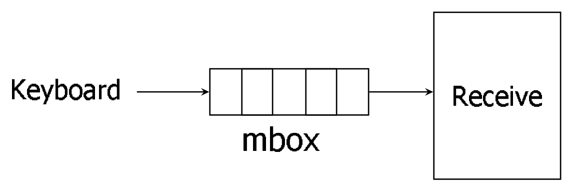
```
#define N 100                              /* number of slots in the buffer */

void producer(void)
{
      int item;
      message m;                           /* message buffer */

      while (TRUE) {
            item = produce_item( );        /* generate something to put in buffer */
            receive(consumer, &m);         /* wait for an empty to arrive */
            build_message(&m, item);       /* construct a message to send */
            send(consumer, &m);            /* send item to consumer */
      }
}

void consumer(void)
{
      int item, i;
      message m;

      for (i = 0; i < N; i++) send(producer, &m);  /* send N empties */
      while (TRUE) {
            receive(producer, &m);         /* get message containing item */
            item = extract_item(&m);       /* extract item from message */
            send(producer, &m);            /* send back empty reply */
            consume_item(item);            /* do something with the item */
      }
}
```

Indirect Communication

- "`dest`" and "`src`" are a shared (unique) mailbox
- Use a mailbox to allow many-to-many communication
  - Requires open/close a mailbox before using it
- Where should the buffer be?
  - A buffer and its mutex and conditions should be at the mailbox

Using Message-Passing

- What is message-passing for?
  - Communication across address spaces
  - Communication across protection domains
  - Synchronization
- Use a mailbox to communicate between a process/thread and an interrupt handler: fake a sender



Process Termination

- P waits for a message from Q, but Q has terminated
  - Problem: P may be blocked forever
  - Solution:
    - P checks once a while
    - Catch the exception and informs P
    - Send ack message
- P sends a message to Q, but Q has terminated
  - Problem: P has no buffer and will be blocked forever
  - Solution:
    - Check Q's state and cleanup
    - Catch the exception and informs P

Message Loss & Corruption

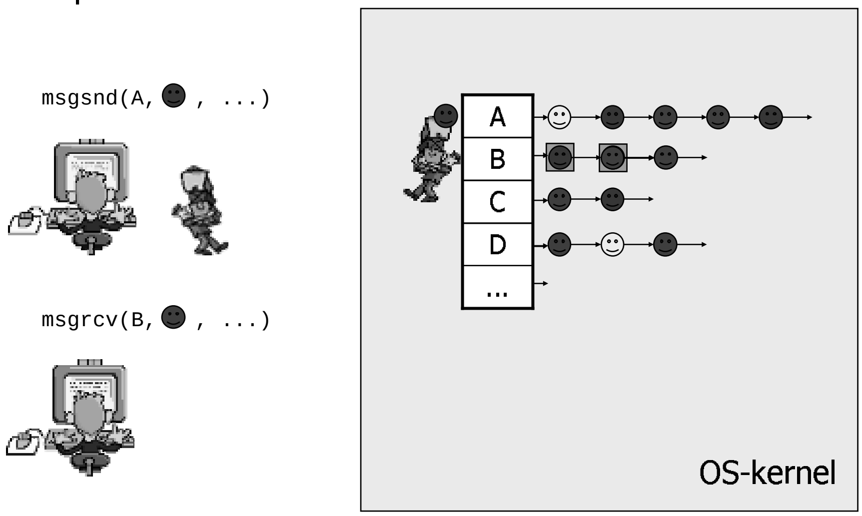
- Unreliable service
  - best effort, up to the user to
- Detection
  - Acknowledge each message sent
  - Timeout on the sender side
- Retransmission
  - Sequence number for each message
  - Retransmit a message on timeout
  - Retransmit a message on out-of-sequence acknowledgement
  - Remove duplication messages on the receiver side

Linux Mailboxes

- Messages are stored as a sequence of bytes
- System V IPC messages also have a type
- Mailboxes are implemented as message queues sorting messages according to FIFO
- Can be both blocking and non-blocking (`IPC_NOWAIT`)
- The next slides have some simplified (pseudo) code
  - Linux 2.4.18
  - several parts missing
  - the shown code may block holding the queue lock
  - waiting queues are more complex
  - ...

Linux Mailboxes

- Example:



Linux Mailboxes

- One `msq_queue` structure for each present queue:

```
struct msg_queue {
        struct kern_ipc_perm q_perm;    /* access permissions */
        time_t q_stime;                 /* last msgsnd time */
        time_t q_rtime;                 /* last msgrcv time */
        time_t q_ctime;                 /* last change time */
        unsigned long q_cbytes;         /* current number of bytes on queue */
        unsigned long q_qnum;           /* number of messages in queue */
        unsigned long q_qbytes;         /* max number of bytes on queue */
        pid_t q_lspid;                  /* pid of last msgsnd */
        pid_t q_lrpid;                  /* last receive pid */
        struct list_head q_messages;
        struct list_head q_receivers;
        struct list_head q_senders;
};
```

- Messages are stored in the kernel using the `msg_msg` structure:

```
struct msg_msg {
        struct list_head m_list;
        long  m_type;              /* message type */
        int   m_ts;                /* message text size */
        struct msg_msgseg* next;   /* next pointer */
};
```

NOTE: the message is stored immediately after this structure - no pointer is necessary

Linux Mailboxes

- Create a message queue using the `sys_msgget` system call:

```
long sys_msgget (key_t key, int msgflg)
{
   ...
   create new message queue and set access permissions
   ...
}
```

- To manipulate a queue, one uses the `sys_msgctl` system call:

```
long sys_msgctl (int msqid, int cmd, struct msqid_ds *buf)
{
   ...
    switch (cmd) {
        case IPC_INFO:
           return info about the queue, e.g., length, etc.
        case IPC_set:
           modify info about the queue, e.g., length, etc.
        case IPC_RMID:
           remove the queue
   }
   ...
}
```

Linux Mailboxes

- Send a message to the queue using the `sys_msgsnd` system call:

```
long sys_msgsnd (int msqid, struct msgbuf *msgp, size_t msgsz, int msgflg)
{
   msq = msg_lock(msqid);
   ...

   if ((msgsz + msq->q_cbytes) > msq->q_qbytes)
         insert message the tail of msq->q_messages *msgp, update msq
   else
         put sender in waiting senders queue (msq->q_senders)

   msg_unlock(msqid);
   ...
}
```

Linux Mailboxes

- Receive a message from the queue using the `sys_msgrcv` system call:

```
long sys_msgrcv (int msqid, struct msgbuf *msgp, size_t msgsz,
                              long msgtyp, int msgflg)
{
   msq = msg_lock(msqid);
   ...
   search msq->q_messages for first message matching msgtype
   if (msg)
         store message in msgbuf *msgp, remove message from msgbuf *msgp, update msq
   else
         put receiver in waiting receivers queue (msq->q_receivers)

   msg_unlock(msqid);
   ...
}
```

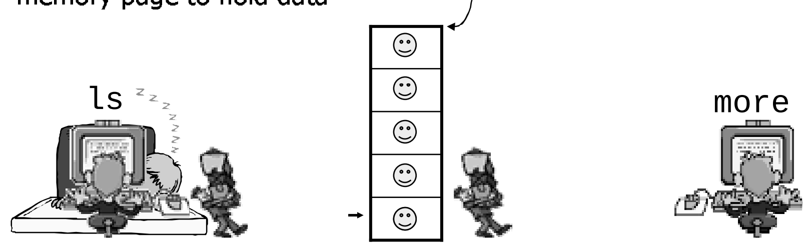
  - the `msgtyp` parameter and `msgflg` flag determine which messages to retrieve:
    - = 0: return first message
    - > 0: first message in queue with `msg_msg.m_type = msgtyp`
    - > 0 & `MSG_EXCEPT`: first message in queue with `msg_msg.m_type != msgtyp`

Linux Pipes

- Classic IPC method under UNIX:
  `> ls -l | more`
  - shell runs two processes `ls` and `more` which are linked via a pipe
  - the first process (`ls`) writes data (e.g., using `write`) to the pipe and the second (`more`) reads data (e.g., using `read`) from the pipe

- the system call `pipe( fd[2] )` creates one file descriptor for reading (`fd[0]`) and one for writing (`fd[1]`) - allocates a temporary inode and a memory page to hold data

```
struct pipe_inode_info {
    wait_queue_head_t wait;
    char *base;
    unsigned int len;
    unsigned int start;
    unsigned int readers, writers;
    unsigned int waiting_readers, waiting_writers;
    unsigned int r_counter, w_counter;
}
```



Linux: Mailboxes vs. Pipes

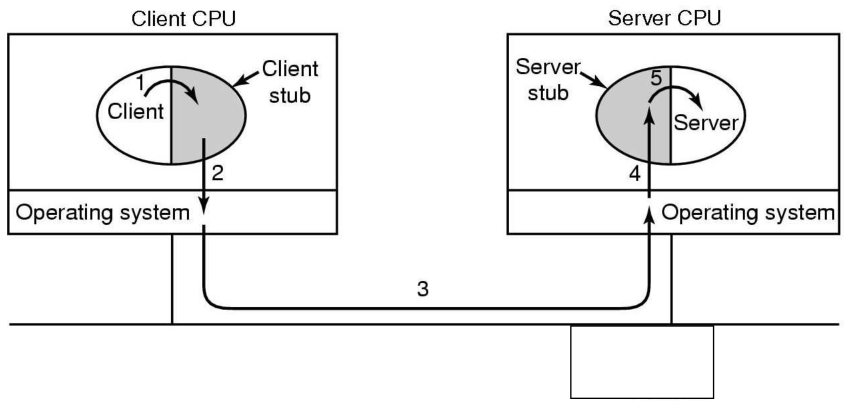
- Are there any differences between a mailbox and a pipe?
  - Message types
    - mailboxes may have messages of different types
    - pipes do not have different types
  - Buffer
    - pipes – one or more pages storing messages contiguously
    - mailboxes – linked list of messages of different types
  - Termination
    - pipes exists only as long as some have open the file descriptors
    - mailboxes must often be closed
  - More than two processes
    - a pipe **often** (not in Linux) implies one sender and one receiver
    - many can use a mailbox

Performance

- Performance is an important issue
  (at least when sender and receiver is on one machine), e.g.:
  - shared memory and using semaphores
  - mailboxes copying data from source to mailbox and
    from mailbox to receiver
- Can one somehow optimize the message passing?

Remote Procedure Call

- Message passing uses I/O
- Idea of RPC is to make function calls
- Small libraries (stubs) and OS take care of communication



Remote Procedure Call

Implementation Issues:

- Cannot pass pointers - call by reference becomes copy-restore
- Marshaling - packing parameters
- Weakly typed languages - client stub cannot determine size
- Not always possible to determine parameter types
- Cannot use global variables - may get moved to remote machine/protection domain

Summary

- Many ways to perform IPC on a machine
- Direct message passing or
  message passing using mailboxes
- Next: INF[34]160